Forecast Systems Laboratory
NOAA Research Review Team Data Request—February 6, 2004

Lab Evaluations: Evaluations from the external Peer Review Team are attached for the FSL Program Review held July 20-21, 1999.

1. FSL HISTORY AND MISSION

The Forecast Systems Laboratory (FSL), located in Boulder, Colorado, was formed in 1988. The primary mission of FSL is to combine the latest insights in the atmospheric, oceanic, and hydrologic sciences with cutting-edge technology in order to develop methods and tools that advance NOAA's research enterprise and the operational capabilities of the National Weather Service. FSL strives for excellence in four major research themes (see Section 3 for more details):

- Developing and bringing new atmospheric observing systems to maturity
- Developing and improving regional mesoscale models for detailed weather predictions
- Investigating parallel computer architectures to handle the huge computational demands of weather forecasting models
- Developing software and hardware systems for new forecasting workstations for a variety of customers, including the NWS, FAA, Air Force, and U.S. Forest Service

In the next **five to ten years**, FSL will continue to play a leading role in supporting NOAA's research mission in these areas by designing new workstation systems that are effective in real-time, highly-demanding operational environments and by developing local and global meteorological observing systems that contribute data required for significantly improving forecast models. FSL will also play key roles in the development of the Weather Research and Forecast (WRF) model, advanced data assimilation techniques, and high-performance computing capabilities. These developments will lead to improved nowcasts, severe weather watches and warnings, quantitative precipitation forecasts, water management, air quality monitoring, fire weather predictions, and regional climate simulations.

2. MAJOR FSL CUSTOMERS

National Weather Service: FSL produces functional designs or working prototypes of techniques, models, workstations, systems, and observation data that may be implemented into National Weather Service (NWS) operations up to a decade later, including the NOAA Profiler Network and AWIPS advancements.

U.S. Air Force: At the request of the Air Force Weather Agency (AFWA), FSL is tailoring the WRF (Weather Research and Forecasting) model to improve Department of Defense (DoD) worldwide mesoscale meteorological modeling for applications to warfighter theaters.

U.S. Army: FSL is tailoring the Local Analysis and Prediction System (LAPS) model for the Army to improve the accuracy of middle-level and high-level parachute delivery of logistical material to military units.

U.S. Department of Transportation: FSL is developing and evaluating the utility of advanced weather display products for FAA Traffic Management Units (TMUs), which are tasked with managing air traffic en route and in airport terminal areas.

Federal Aviation Administration: FSL supports the Federal Aviation Administration through several projects, including: the Aviation Digital Data Service (ADDS), which is an Internet-based forecast system that provides up-to-the-minute observations and forecasts for specific flight routes; the development of convective forecasts that display prototype in-flight icing products; verification systems that focus on aviation weather forecasts and tools that allow forecasters to generate and display statistical information in near real-time; model predictors of air turbulence and research to better understand turbulence generation mechanisms.

Federal Highways Administration: FSL was part of a collaborative efforts to field-test the Maintenance and Decision Support System, a model-based system that supports snow plow operators with timing and chemical use decisions, and to procure and install GPS Surface Meteorological Sensor (GSOS) equipment packages as part of the Nationwide Differential Global Positioning System (NDGPS).

Department of Agriculture/US Forest Service: FSL is developing an analysis and modeling capability that encompasses needed fire-specific (both planning and incident) support products, including forecast model software for the Rocky Mountain Fire Weather Modeling Center.

Department of Interior/BLM: The National Interagency Fire Center (NIFC) requested that FSL develop a real-time meteorological workstation for use by fire weather forecasters at NIFC, and that FSL support the system during the fire season.

U.S. Department of Energy/NREL: FSL continues a collaborative wind energy study with the National Renewable Energy Laboratory (NREL) that utilizes 20-km RUC/MAPS forecasts.

National Aeronautical and Space Administration: FSL supports the Johnson Spaceflight Center by tailoring an AWIPS system with FX-Collaborate to provide weather briefings prior to Space Shuttle landings.

Lockheed Martin: FSL is providing AWIPS-like workstation systems and LAPS models in support of Lockheed Martin's effort to provide forecasts for rocket launches and the daily operations of the U.S. Space Launch facilities at Vandenberg Air Force Base, CA, and Cape Canaveral Air Station, FL.

Taiwan Central Weather Bureau: FSL's continuing collaboration with the Central Weather Bureau of Taiwan has been a 13-year success story in technology transfer of weather forecasting and modeling systems.

Korean Meteorological Administration: FSL is assisting the Meteorological Research Institute of the Korean Meteorological Administration in the design of a nowcasting system based on AWIPS.

3. SUMMARY OF FSL RESEARCH

- **Developing and Bringing Atmospheric Observing Systems to Maturity**

FSL conducts research to evaluate promising new atmospheric observing technologies and to determine their value to operations. Activities range from demonstrations of scientific and engineering innovations to the management of new systems and technologies. In support of NOAA's mission to serve society's need for weather and water information, FSL uses new upper-air observing techniques to create and disseminate reliable assessments of weather, climate, space environment, and geodetic phenomena. FSL has also led the research efforts to determine how to use ground-based Global Positioning System (GPS) sensors for providing a measurement of the integrated precipitable water vapor for use in data assimilation and numerical weather prediction systems.

In order to continue to explore the use of various types of data in weather research and forecasts, FSL gathers atmospheric observations from multiple sources. For example, the number of Cooperative Agency Profilers, most of them sampling the boundary layer, has grown to over 60. The number of ground-based GPS sites now exceeds 300. More than 5,000 new surface mesonet observations have been added to the FSL hourly collection. After performing quality control checks, FSL forwards all these data to the National Centers for Environmental Prediction (NCEP) for use in operational modeling and data assimilation.

FSL is developing plans for a global observing system with major in situ components that can address the controversy regarding long-term tropospheric warming, as well as monitor natural and anthropogenic atmospheric constituents and sample the ocean depths. This system would meet requirements for climate monitoring and prediction and also provide much needed calibration of satellite observations in remote locations. The first phase of this program, called "Pacific Plus," would employ a combination of unpiloted aircraft, altitude-controlled balloons, and ocean buoys to sound the atmosphere and water across the length and breadth of the Pacific.

Gauging the contributions of various observing systems to forecast accuracy is an important activity. FSL recently completed the modeling and computing infrastructure for performing such impact tests. Because commercial airlines, which supply nearly 100,000 temperature and wind reports per day, are financially strapped, and the benefits of the NOAA Profiler Network were unclear to Congress, FSL conducted special impact tests, demonstrating that aircraft and profilers contribute substantially to forecast accuracy and that these data are highly complementary.

Major FSL observing projects include:

NOAA Profiler Network (NPN): FSL manages, operates and maintains the NOAA Profiler Network (NPN), consisting of 32 wind profilers located mostly in the central United States, and also processes data from over 60 Cooperative Agency Profilers located throughout the U.S. This combined data is provided with high reliability to the National Weather Service. The NPN relates to NOAA mission goal 3, Weather and Water, and the Local Forecasts and Warnings program. Its geographical scope is national. Beginning in FY 2004, the NPN will transition from FSL to

National Weather Service operations. Long-term research to modernize and improve the NPN will be conducted by FSL in conjunction with NWS.

GPS Water Vapor Monitoring System (GPS-Met): FSL has developed and operates a prototype operational ground-based Global Positioning System (GPS) water vapor monitoring system of over 300 sites—the first system of its kind in the world. Activities include demonstrating the positive impact of GPS data on weather forecasts and assisting in the transition of these techniques to operational use. The water vapor data is shared with the National Weather Service, the National Environmental Satellite and Data Service, the National Ocean Service, other NOAA Research programs and laboratories, and the Departments of Defense, Energy, Homeland Security, and Transportation. GPS-Met relates to NOAA Mission Goal 3, Weather and Water, and the Weather and Water Science and Technology Infusion Program. Its geographical scope is national and global depending on the needs of other agencies, and research on GPS meteorology is anticipated to be long term.

Meteorological Assimilation Data Ingest System (MADIS): The objective of MADIS is to support the meteorological research and operations by sharing surface observations from a large variety of sources with government, research and educational institutions which are part of the greater meteorological community. MADIS makes value-added data available from FSL's supercomputer with the goal of improving weather forecasting, by providing support for data assimilation, numerical weather prediction, and other applications. Over 5,000 new surface mesonet observations have been added to the FSL hourly collection. Datafeeds are provided to the NWS forecast offices, NCEP, the National Center for Atmospheric Research (NCAR), NOS, NASA's Marshall and Kennedy Space Flight Centers, and many others. MADIS relates to NOAA mission goal 3, Weather and Water, and cuts across the programs for Local Forecasts and Warnings, Environmental Modeling, and Science and Technology Infusion. Its geographical scope is national and the research timeframe is long term.

- **<u>Developing and Improving Regional Mesoscale Models for Detailed Weather Predictions</u>**

FSL is a leader in the development of advanced numerical weather prediction (NWP) modeling and data assimilation techniques. A major emphasis involves the assimilation of operational, research, and future meteorological observations for analyzing current atmospheric conditions and the subsequent generation of short-range numerical forecasts. Produced in real time at frequent intervals on national and local scales, these analyses and forecasts are valuable to commercial aviation, civilian and military weather forecasting, the energy industry, regional air pollution prediction, and for emergency preparedness.

FSL's research includes three models: the Rapid Update Cycle (RUC), the Local Analysis and predictions System (LAPS), and the Weather Research and Forecasting (WRF) model. The RUC is a complete analysis/forecast system for hourly assimilation of meteorological observations over the United States into a numerical prediction model; the RUC has been implemented as an operational forecast system at the NWS National Centers for Environmental Prediction (NCEP). LAPS incorporates local datasets into numerical models for the production of very detailed analyses of local weather conditions and short-range forecasts. WRF is under development by the modeling community to serve as a community model for both forecasters and researchers.

Major numerical modeling and data assimilation projects include:

Mesoscale Analysis and Prediction System (MAPS/RUC)*:* The Rapid Update Cycle (RUC) is a complete analysis/forecast system for hourly assimilation of meteorological observations over the United States into a numerical prediction model. FSL develops and tests improvements to the RUC and its research counterpart, MAPS, and will continue to work with scientists at NCEP, NCAR and other organizations to improve RUC. For example, the three-dimensional variational analysis became operational in the 20-km version of RUC in May 2003. MAPS/RUC relates to NOAA mission goal 3, Weather and Water, and the Environmental Modeling program. Its geographical scope is national with a long-term research timeframe.

Weather and Research Forecast Model (WRF)*:* The overall goal of the WRF model project is to develop a next-generation mesoscale forecast model and assimilation system that will advance both the understanding and prediction of important mesoscale weather, and promote closer ties between the research and operational forecasting communities. FSL has worked on the development of physics pacakages, a three-dimensional (3DVAR) analysis system, and the standard initialization package. FSL will adapt WRF assimilation and model systems to include an advanced rapid update capability for operational implementation at NCEP. FSL will port WRF to its high performance computer to enable completion of the WRF test plan. A developmental testbed center (DTC) for WRF will be established at FSL. WRF relates to NOAA mission goal 3, Weather and Water, and the Environmental Modeling program. Its geographical scope is national with a components in all time frames.

Local Analysis and Prediction System II (LAPS): LAPS is a system that integrates data from virtually every meteorological observation system into a very high-resolution gridded framework centered on a NWS forecast office's domain of responsibility. The data from local meso-networks of surface observing systems, Doppler radars, satellites, wind and temperature profilers, and aircraft are incorporated every hour into a three-dimensional grid. LAPS has both analysis and prediction components applicable to operational weather offices, facilities, or field operations. LAPS supports mostly government and military entities, including the NWS, FAA, FHWA, the Air Force Weather Agency, and DOD. LAPS relates to NOAA mission goal 3, Weather and Water, and the Environmental Modeling program. Its geographical scope is regional (but across the U.S.) with a medium term research timeframe.

Other Modeling Projects: FSL is involved in a variety of other projects including the International H2O Project (IHOP), Health of the Atmosphere, Temperature and Air Quality Forecasting Program, AIRMAP, and the Joint Center for Satellite Data Assimilation (JCSDA), where FSL develops, analyzes, evaluates, or adapts models for various purposes. These ongoing projects also relate to NOAA mission goal 3, Weather and Water, and the Environmental Modeling program. Geographical scope is regional except for JCSDA which is national in scope. Research time frames are medium term except for JCSDA which is long term.

Other Meteorological Applications: FSL participates in the U.S. Weather Research Program, THORPEX, and other collaborative projects.

- **Investigating Parallel Computer Architectures for Handling Weather Forecasting Models**

FSL has pioneered the use of Massively Parallel Processing (MPP) computer systems for numerical weather prediction, and is now one of three supercomputing centers in NOAA. Modern parallel supercomputers, typically composed of commodity off-the-shelf components, offer a less costly alternative to traditional vector supercomputers for the fast, efficient production of numerical forecasts. A recent upgrade to FSL's supercomputer added 1,536 Pentium nodes making it the 8th fastest computer at the time of installation. This computer is used for numerical-weather model development, WRF model testing, as well as being available for users outside of FSL. Currently, FSL is in the process of developing new requirements for the procurement of the next high performance computer. High performance computing relates to NOAA mission goal 3, Weather and Water, and to the Environmental Modeling program. Its geographical scope is national to global with a medium- to long-term research time frame.

FSL has also developed software tools and techniques to make the best use of the MPPs. This software simplifies the porting of numerical geophysical models from FSL, other NOAA/OAR laboratories, the National Centers for Environmental Prediction (NCEP), and other organizations to modern parallel computing architectures. The principal tool is the Scalable Modeling System (SMS) which significantly enhances the ability to develop parallel finite-difference weather models and provides source code portability between a large subset of existing MPPs.

- **Developing New Forecasting Workstations and Systems**

FSL performs exploratory development of advanced system concepts and technology for meteorological display systems, and transfers these into operations. Past explorations have included investigation of new techniques for user interfaces, data display, system architectures, and software design and programming. The most recent exploratory work includes the use of Linux for meteorological workstation development, interactive 3D data visualization, and graphic tool development for remote collaboration. FSL develops operational prototype systems using these new techniques and technologies, and performs limited operational evaluation and testing of these systems.

Capitalizing on major development work at FSL, the National Weather Service is installing Linux-based workstations at each of its Weather Forecast Offices around the country. These workstations replace the Hewlett-Packard hardware that inaugurated the Advanced Weather Interactive Processing System (AWIPS) era. The highly robust Linux was developed in an open-source environment and runs on nonproprietary hardware.

Major workstation and software systems projects include:

Advanced Weather Information Processing System (AWIPS)*:* With AWIPS now deployed nationwide at NWS, the focus is on adding new data and functions that enhance the warning and forecast mission of NWS. A major effort is the transition to grid based forecasting which uses the Graphical Forecast Editor developed at FSL. AWIPS relates to NOAA mission goal 3, Weather and Water, and the Science and Technology Infusion Program. It is national in scope with both short and medium term research components.

Collaborative Weather System (FXC)*:* FXC is a Java application that provides users access to a variety of meteorological data stored in remote AWIPS databases and on Web servers and local disks. It has the ability to interlink a number of remote systems to conduct real-time weather briefings, live meteorological discussion, or long distance learning through its collaborative capabilities. Users include the USAF launch facilities at Vandenberg AFB and Cape Canaveral Air Force Station, NASA Johnson Space Flight Center, and some NWS Weather Forecast Offices. Further development of FXC will continue as users are added and their data display and coordination needs must be met. FXC relates to NOAA mission goal 3, Weather and Water, and the Science and Technology Infusion Program. Its geographic scope is regional and national with a medium-term time frame.

FX-Net*:* FX-Net is a meteorological PC workstation that provides access to the basic capability of an AWIPS workstation via the Internet. The AWIPS workstation user interface is emulated very closely. Bandwidth limitations are addressed by using new wavelet data compression techniques developed at FSL, along with multithreaded client-side processing and communication. FX-Net is used to provide fire weather support for the meteorologists at the National Interagency Fire Center and their 11 Geographic Area Coordination Centers. FX-Net systems have also been provided to the NWS Western, Southern, Alaska, and Pacific regions with the ability to support Incident Meteorologists (IMETS) in the field for events such as the California wildfires and mudslides and the Colorado Hayman fire. Development of FX-Net will continue to add products to support customer needs. FX-Net relates to NOAA mission goal 3, Weather and Water, and to the Science and Technology Infusion Program. Its geographic scope is national with a medium-term time frame for the project.

Volcanic Ash Coordination Tool (VACT)*:* This was developed by FSL to support the NWS Aviation Initiative for implementation at the Alaska Volcanic Ash Advisory Center, the Anchorage Center Weather Service Unit, and USGS Alaska Volcano Observatory. The VACT will facilitate timely generation of fully-consistent advisories and warnings for volcanic ash. VACT relates to NOAA mission goal 3, Weather and Water, and the Science and Technology Infusion program. Its geographic scope is global with a short- to medium-term time frame for the project.

Aviation Weather Products*:* FSL created the Aviation Digital Data Service (ADDS) which is a suite of operational and experimental weather products for use by pilots and dispatchers; the Real Time Verification System (RTVS) which determines the quality of a spectrum of aviation weather products; productivity tools for use by staff of the NWS's Aviation Weather Center in preparing forecasts of flight hazards; and products for FAA traffic managers at Air Route Traffic Control Centers. These aviation weather products relate to NOAA mission goal 3, Weather and Water, and to the Science and Technology Infusion Program except for RTVS which belongs in the Environmental Modeling program. Geographical scope extends from regional to national with time frames extending from short- to medium-term.

4. MAJOR FSL ACCOMPLISHMENTS

Forecast System Laboratory's mission is to transfer scientific and technological advances to the nation's operational weather and climate services. Its primary customers have been the operational weather organizations of the U.S., mainly the National Weather Service. The public benefits from the resulting improved services of NWS. A few of the most important successes follow.

Core scientific and technical resource for the primary information system of the National Weather Service.

FSL has been, and continues to be, the core scientific and technical resource used by the National Weather Service in its Advanced Weather Interactive Processing System (AWIPS). AWIPS is the central information system of the NWS, and was in serious jeopardy in the late 1990s. The problem was that the system as implemented by NWS contractors was far behind schedule and unable to meet its requirements. The decision by NWS management to use the core capabilities developed by FSL (including the display system, data base, and dissemination system) led to a successful operational implementation of AWIPS. If FSL had not developed the system the NWS may well have ended the AWIPS procurement in failure, leaving a far inferior system in place during the period of the last five years and into the future. Instead, AWIPS success capped the completion of the modernization, which has resulted in a big improvement of NWS services. Most notably, the tornado outbreaks of May 1999, and May 2003 would probably have taken 500 to 1000 additional lives had not the modernized NWS been in place.

The role of FSL in keeping AWIPS current technologically has continued. Several years ago, FSL used its base funds to develop a Linux based AWIPS workstation. Although this effort was initially discouraged by NWS, a decision was made by NWS management in the year 2000 to test and implement Linux workstations in all offices nationwide. This program has been highly successful, making AWIPS much more responsive with resulting improvements in timeliness and skill in NWS forecasts and warnings. In addition to hardware upgrades such as the Linux systems, FSL has played a major role in the ongoing upgrades of AWIPS, and keeping it scientifically advanced as new concepts come from the research community.

FSL continues to be core provider of key parts of the AWIPS. It played a key role in the development of the National Digital Forecast Database (NDFD), which has been implemented this year in NWS. This system allows forecasts to interact in sophisticated ways with model prediction databases. The forecasters can construct a high resolution database that allows their ideas of time and space sequences of weather parameters to be put into a digital prediction database. These are mosaiced among weather offices to make a national prediction of key weather parameters. The digital database is then the basis for very detailed worded forecasts; pick any point in the U.S., and a worded forecast can be generated.

FSL has developed several other systems using its base funds that are now widely used by NWS. For example, the FX Net, which allows AWIPS capabilities to be deployed over low bandwidth communications, was very important in helping NWS with its fire weather program during the last couple of years.

FSL has developed, upgraded and supported one of the primary operational models of the NWS: The Rapid Update Cycle (RUC).

FSL began work in the 1980s to develop a new class of model for NWS, designed to give very accurate and frequent short range weather predictions. It has continued to be the sole development and support for this important model. The RUC has been fully operational at NWS's National Center for Environmental Prediction for the last 10 years. It runs every hour, and makes predictions out to 12 hours. It uses a three dimensional variational analysis system that makes use of numerous types of data. The RUC model is advanced in a number ways. It uses an isentropic coordinate system above the boundary layer, which has excellent conservation properties. It has been the leader in the use of high temporal resolution data in its assimilation. For example, it uses hourly profiler, aircraft, radar, satellite and surface data. It has been very important for short range prediction of severe weather, and in support of aviation and other forms of transportation. The hourly surface analysis used by the NWS in AWIPS, the MSAS, has also been built and maintained by FSL.

In 1998, NCEP, NCAR and FSL joined forces to develop the next generation of mesoscale model, called the Weather Research and Forecast (WRF) model. This system is under development, with an important component of the testing and development being done at FSL.

FSL continues leadership in high performance computing.

In 1988, FSL began work on massively parallel computing, based on a judgment that this would become the future operational paradigm for operational weather prediction. Despite protestations that "massively parallel machines will never replace parallel vector computers", it happened in 1999 when NWS purchased its first such computer. By that time, the benefits of a decade of experience were available to NWS, and other operational organizations worldwide as they converted their operations. FSL personnel were involved in the development of the message passing standards that made this possible. Recently, FSL has been pursuing the use of commodity processors to get maximum computing per dollar. FSL's Jet Supercomputer was upgraded to almost 2000 Pentium 4 processors in late 2002, and was benchmarked as the 8th fastest computer in the world, although its cost is far less than computers of similar speed. This is paving the way for use of commodity clusters for a number of future operational uses.

The technology transfer of high temporal resolution weather data.

FSL has been able to make high resolution weather data available for use by NWS in a number of ways. It has operated a wind profiler network in central U.S. for 10 years, and is working with the NWS to design a national network for operations. Its profiler network has been the key to severe weather prediction improvements. FSL has developed the use of ground based Global Positioning System moisture estimates, which has recently been implemented and is improving operational NWS models. FSL was the first organization to work with the airlines to make automated aircraft data ("ACARS") routinely and comprehensively available. In recent years the FSL aircraft sounding display system has been used routinely by NWS and other operational forecasters. FSL's

high resolution surface mesonet display has been widely used and lauded within NWS and throughout the meteorological community.

5. LEGAL MANDATES AND FINANCIAL DATA

FSL has no specific legal mandates but assists NOAA in complying with the Weather Service Organic Act and the Weather Service Modernization Act through FSL research and technology transfer. The FY 2003 financial data provided for FSL are correct.